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NUMERICAL ANALYSIS OF HAIL ICE MATERIAL MODEL UNDER VARIABLE VELOCITY IMPACT

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ABSTRACT

Hail ice impact events are very usual and hazardous to aircraft structures particularly in adverse weather. Hail ice impact falls under the preview of the Foreign Object Damage (FOD) and the aircraft structures are required to be validated for certification of the aircrafts. Numerical simulation is an cost effective method before the experimental studies. The modeling of the hail ice characteristics is a significant challenge in area of the soft body impact. Hail Ice is modeled using Lagrangian Method and is used effectively in impact application. This paper presents load-time history and peak force for each impact and is quantified for hail ice with variable diameter of 12.7mm, 25.4mm and 38.1mm. Numerical simulation is done using commercially available code LS-DYNA with variable velocities between 25 – 150 m/s. An increase of 96% peak force was found at 150 m/s impact velocity with hail ice diameter varying between 12.7mm to 38.1mm and mass variation of 0.89g to 23.68g.

KEYWORDS: Hail ice, Impact, Foreign Object Damage & Numerical Simulation

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Original Article

INTRODUCTION

Numerical simulation forms importance part of design in aerospace industry. Numerical simulation has gained wide acceptance as destructive tests are known to be expensive. The main constituents of impact test are projectile and target. Numerical simulation can accurately predict the behavior of composite and metallic elements in large deformation conditions prompted by high velocity impact. This is because of the improvement of the modeling the structure. In this paper, we have tried to model the hail ice properties under different impact velocities. The hail ice could impact the different parts of aircraft which includes leading edges, canopy, and nose structure of aircraft, fuselage and engine components. Since ice impact is a grave threat for aircraft, we need to increase the knowledge of this event. The experiments with space shuttle thermal protection systems were subjected to hail ice impact with variable velocities were carried out by DeWolfe, P. H [1]. The dependence on temperature microstructure and strain rate was investigated by several researches [2-5]. Petrovic JJ et al. carried out experiment on strain rate and temperature variation in hail ice and found out the tensile strength is independent of this parameters [6]. Jones SJ found out that compressive strength of hail ice is very sensitive to strain rate and temperature due to increase use of composite structures in aircraft makes it importance of understanding the force induced by hail Ice impact[7] Many researchers have investigated the hail ice impact on composite laminates. Kim et al. conducted several experiments on hail ice impact on composite laminates [8-11]. Different diameters of hail ice were analyzed to find the influence on force-time history and the maximum peak load exerted by the hail ice. The harmful effects of the impact of ice at

high speeds are well known. To endorse the safety of the design, tests are usually required for man-rated vehicles. Concerning the catastrophic result of hail on high velocity impact on flying vehicles, the safety of the design is required to be certified. The geometry of hail plays a key role in damaging flying vehicles and Space Shuttle. Impact phenomena demands a complete mixture of ideas and data gathered from experiments, theory and computation. A tragic and dangerous impact effect on the Columbia Space Shuttle disaster is a familiar case caused by impact damage. In recent years, the focus of research has turned towards numerical modeling of soft body impact behavior under high velocity conditions irrespective of geometry.

MATERIAL MODELING OF HAIL ICE AND RIGID TARGET

The modeling and simulation of hail ice and target plate were done using explicit finite element (FE) code LS-DYNA. The hail ice element was modeled using the material parameters given in the table. Different geometries of hail ice having diameters of 12.7mm, 25.4mm and 38.1mm were modeled. Non-iterative plasticity with simple plastic strain failure model MAT_ISOTROPIC_ELASTIC_FAILURE material Type 13 was selected to model the hail ice. In this model the element loses its ability to carry tension and the deviatoric stresses and the material behaves like a fluid when the effective plastic strain reaches the failure strain or when the pressure reaches the failure pressure. The material properties and material parameters for hail ice of density 846kg/m^3 are given in the table 1 and 897kg/m^3 are given in the table 2. Target plate material parameters for LS-DYNA simulation are given in table 3. MAT_PIECEWISE_LINEAR_PLASTICITY, Material Type 24 is used to define material properties for the target plate and the material parameters for the target plate are given in the table 2. The hail ice was modeled with 1512 elements and 1651 nodes and the target plate was modeled with 2880 elements and 3355 nodes. Simulation is carried out by changing the hail ice diameters and giving impact velocities of 25, 50, 75, 100, 125 and 150m/s.

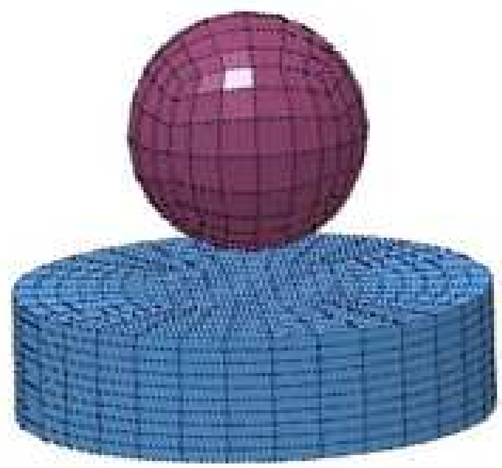

Figure 1: Finite Element Model of Hail Ice and Target Plate.

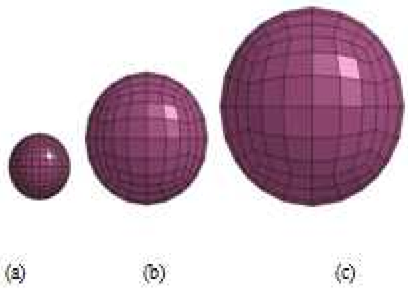

Figure 2: Numerical Model of Hail Ice with Varied Diameter. (a) 12.7mm (b) 25.4mm (c) 38.1mm.

Table 1: Ice Material Parameters for LS-DYNA Simulation 846 kg/m^3

Density (kg/m3)	Elastic Shear Modulus (GPa)	Yield Strength (Mpa)	Hardening Modulus (Gpa)	Bulk Modulus (Gpa)	Plastic Failure Stain %	Tensile Failure Pressure (Mpa)
846	3.46	10.30	6.89	8.99	0.35	-4.0

*Negative sign denotes hydrostatic tension stress.

Table 2: Ice Material Parameters for LS-DYNA Simulation with Density 897 kg/m^3

Density (kg/m3)	Elastic Shear Modulus (GPa)	Yield Strength (Mpa)	Hardening Modulus (Gpa)	Bulk Modulus (Gpa)	Plastic Failure Stain %	Tensile Failure Pressure (Mpa)
897	3.48	10.30	6.9	8.99	0.38	-4.0

*Negative sign denotes hydrostatic tension stress.

Table 3: Target Plate Material Parameters for LS-DYNA Simulation

Density (kg/m3)	Young's Modulus (GPa)	Poisson's Ratio	Yield Stress(Mpa)	Tangent Modulus (Mpa)
7870	210	0.33	400	400

RESULTS AND FINITE ELEMENT SIMULATION

The finite element simulations were carried out in LS-DYNA software and the results are quantified. The simulation is carried out for velocities of 25, 50, 75, 100, 125 and 150m/s. The Contact force-time histories for 12.8mm hail ice model at different velocities are shown in the figure 3. The Contact force-time histories for 25.4mm hail ice model at different velocities are shown in the figure 4. The Contact force-time histories for 38.1mm hail ice model at different velocities are shown in the figure 5. The figure 6 to figure 8 shows the pressure time history of 12.7mm, 25.4mm and 38.1mm respectively. The maximum peak-force of hail impact with different diameter of hail ice is taken from the force time history and the pressure time history. The hail ice impact event at different time steps is shown in figure 2.The progressive failure of the ice on impact at different time steps is shown for different time steps.

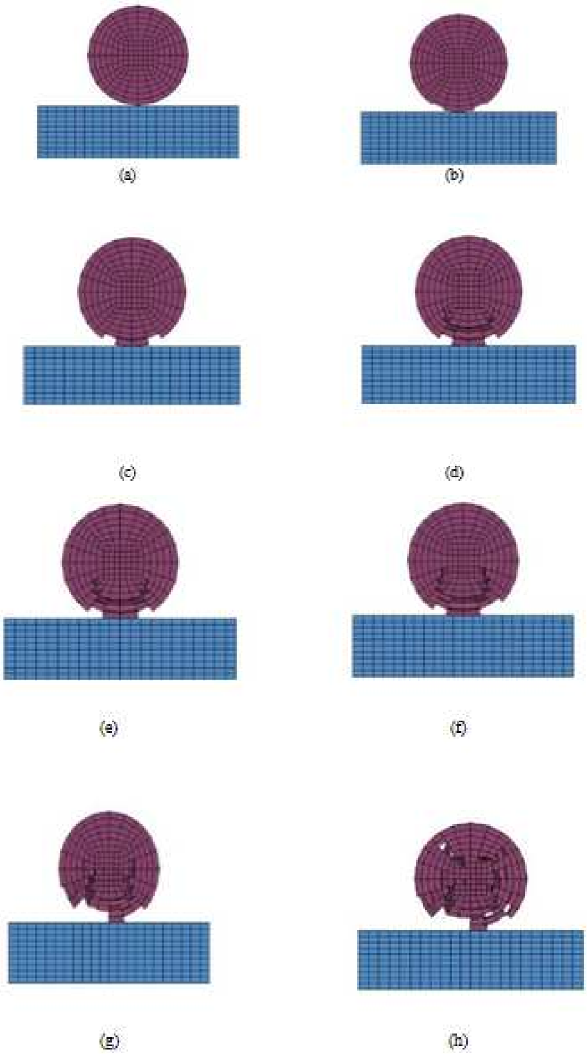

**Figure 3: Hail Ice Impact at 75m/s.
(a) 0ms (b) 0.01ms (c) 0.02ms (d) 0.03ms.
(e) 0.04ms (f) 0.05ms (g) 0.06ms (h) 0.07ms.**

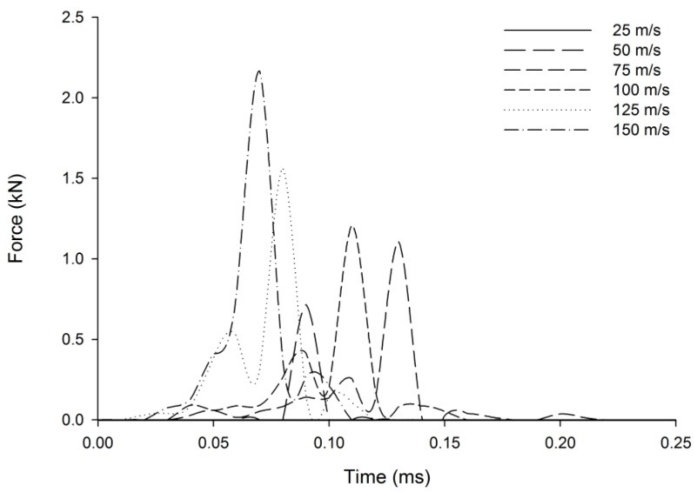

Figure 4: Contact Force-Time History for 12.8mm Diameter Hail Ice.

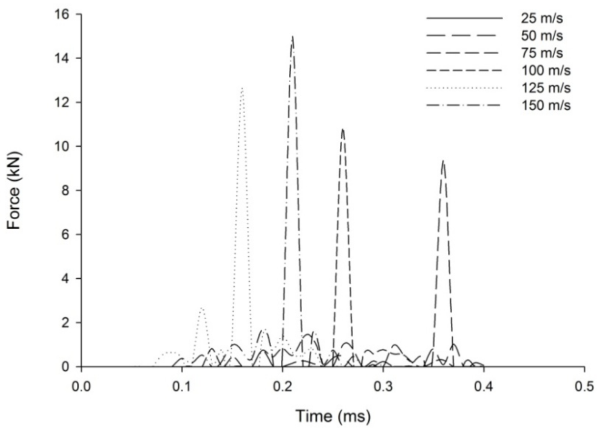

Figure 5: Contact Force-Time History for 25.4 mm Diameter Hail Ice.

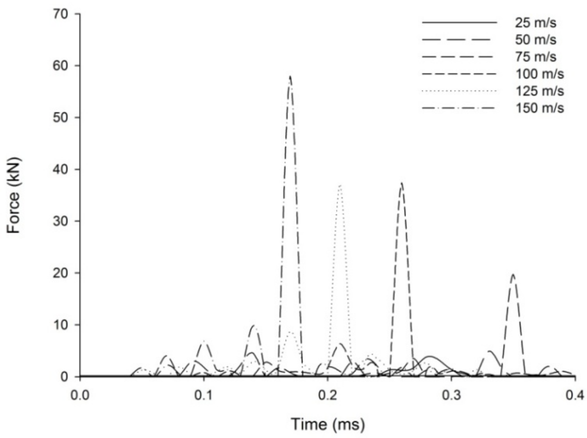

Figure 6: Contact Force-Time History for 38.1mm Diameter Hail Ice.

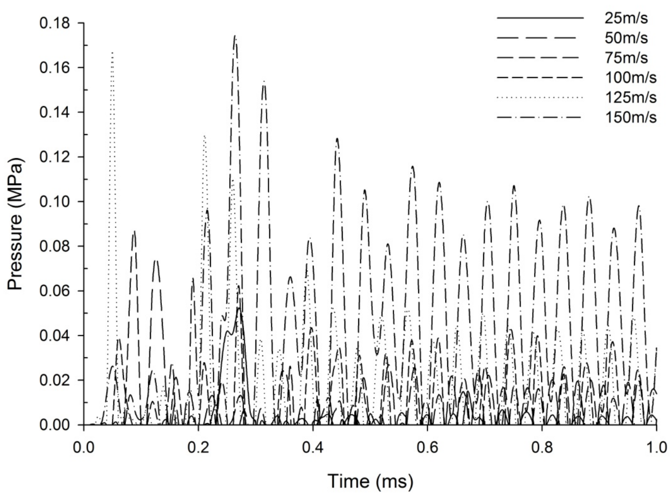

Figure 7: Contact Pressure-Time History for 12.8mm Diameter Hail Ice.

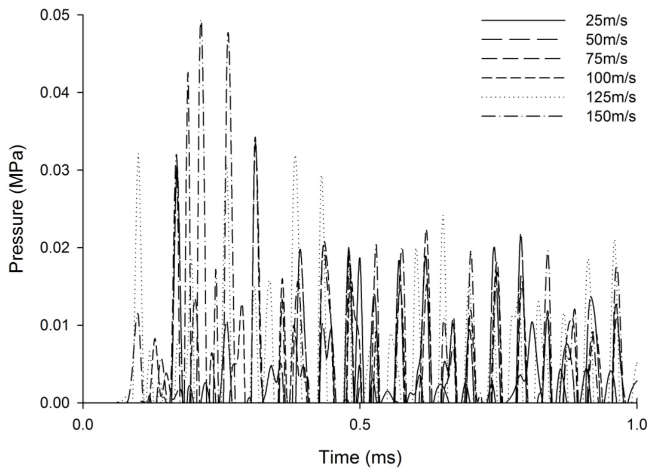

Figure 8: Contact Pressure-Time History for 25.4mm Diameter Hail Ice.

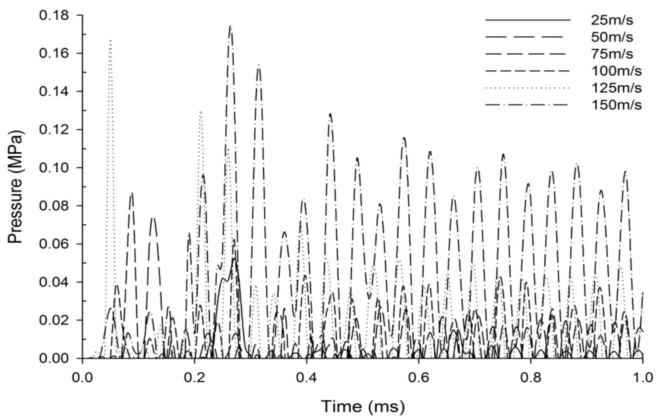

Figure 9: Contact Pressure-Time History for 38.1mm Diameter Hail Ice.

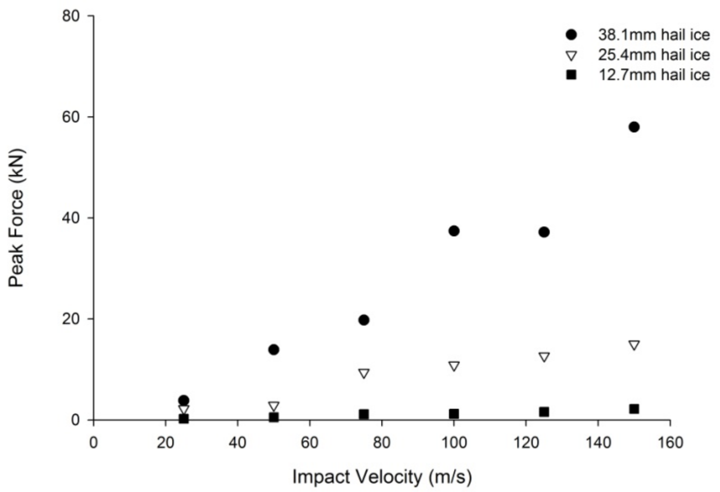

Figure 10: Summary of Peak Force for Different Diameters of Hail Ice.

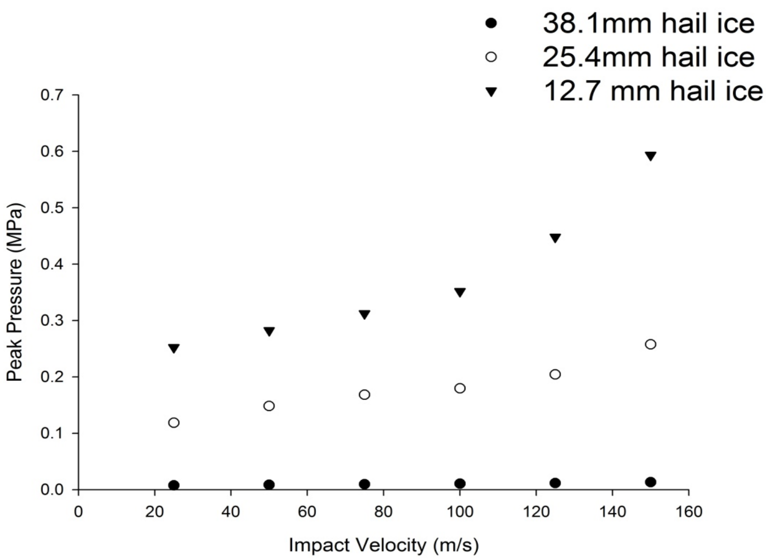

Figure 11: Summary of Contact Pressure-Time for Different Diameters of Hail Ice.

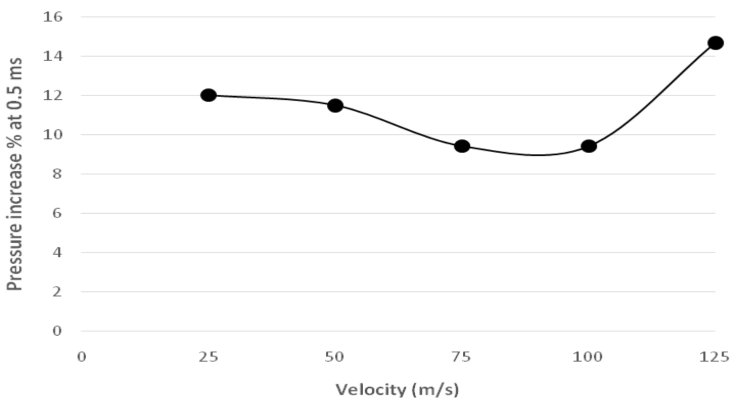

Figure 12: Summary of Pressure Increment Percentage with Velocity at 0.5 ms.

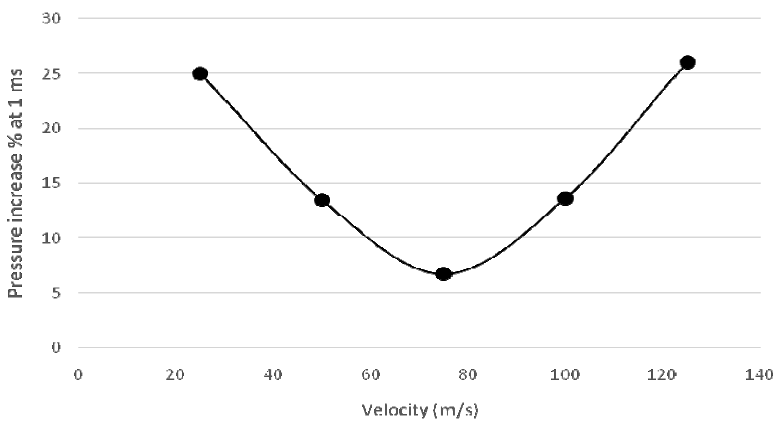

Figure 13: Summary of Pressure Increment Percentage with Velocity at 1 ms.

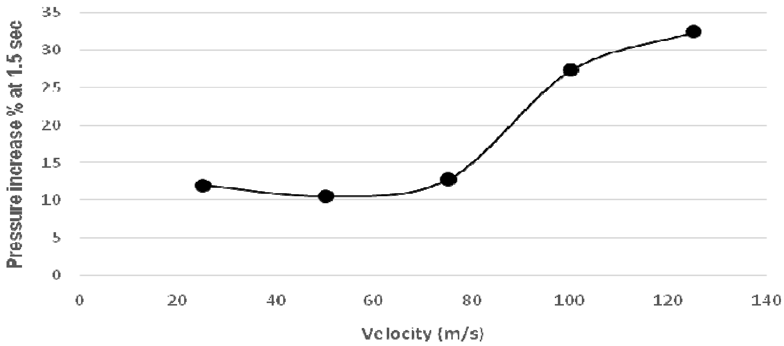

Figure 14: Summary of Pressure Increment Percentage with Velocity at 1.5ms.

From the figure 11, for the time interval from 0ms to 0.5ms, a gradual decrease in the pressure increment percentage from 25 m/s to 100 m/s velocity and sudden rapid increase is found reaching 125 m/s velocity. From the figure 12, for the time interval 0 ms to 1ms, a gradual decrease in pressure increment percentage from 25 m/s velocity to 50 m/s is found and then gradual increase takes until 75 m/s velocity followed by rapid increment until 100 m/s velocity and again gradual increase in velocity is found. From figure 13, for the time interval of 0 ms to 1.5ms, slope decrease in the pressure increment percentage from 25 m/s to 75 m/s velocity is found and slope increment is followed until 125 m/s.

CONCLUSIONS

In this work, the numerical analysis of hail ice model with respect to the force induced by the variable velocity impact is accomplished. Variable velocity test simulations are carried out for different diameters of hail ice using LS-DYNA. Size and impact velocity posses a hazardous effect to aircraft structures. At a minimum, hail may impact aircraft on the ground at falling terminal velocity between 30m/s to 50 m/s, but at the other end of the spectrum, they may impact aircraft at in-flight speeds of 200 m/s or greater. When hailstones exceed 0.5 inches (13 mm) in diameter, planes can be seriously damaged. The hailstone accumulating on the ground can also be hazardous to landing aircraft. The peak force and pressure variation at different impact velocities are shown in figure 9 and figure 10. From 25m/s to 150 m/s the force history shows 93.4% increase in peak force for 38.1mm diameter hail ice. From 25m/s to 150 m/s the force history shows 85.2% increase in peak force for 25.4mm diameter hail ice and 89.8% increase in peak force for 12.7mm hail ice. At 150m/s the peak force shows exponential increase of 96% from 12.7mm to 38.1mm diameter hail ice.

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